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Q-Band (45 GHz) Microwave Integrated Circuit Power Amplifier Designs Submitted to TriQuint Semiconductor for Fabrication with 0.15-µm High-Electron-Mobility Transistors (HEMT) Using 2-mil Gallium Nitride (GaN) on Silicon Carbide (SiC)

by John E. Penn

ARL-TN-0574 **September 2013**

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John E. Penn
Sensors and Electron Devices Directorate, ARL

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14. ABSTRACT
Compact hand-held satellite communications (SATCOM) systems are important for instant, secure data, and voice links in remote global regions. Small efficient electronic components are needed for these, often battery powered, communications systems, particularly the power amplifier (PA) circuit in the transmitter. Gallium nitride (GaN) integrated circuits enable improvements in power efficiencies, transmit powers, and higher bandwidths for state-of-the-art radio frequency (RF) electronics and devices. The U.S. Army Research Laboratory (ARL) has been working with TriQuint Semiconductor, Inc. (TQS) for fabrication under a recent cooperative research and development agreement (CRADA) between ARL and TQS to develop efficient high-power amplifiers for SATCOM applications. Several Q-band amplifier designs were submitted for fabrication in a TQS pre-released 0.15-µm GaN on the 2-mil silicon carbide (SiC) process. This technical note gives a brief overview of the designs submitted for fabrication which that will be followed by a more thorough technical report on the design details of those PAs.

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1. Introduction

Compact handheld satellite communications (SATCOM) systems are important for instant, secure data, and voice links in remote global regions. Small efficient electronic components are needed for these, often battery powered, communications systems. A vital component in that SATCOM link is the power amplifier (PA) circuit in the transmitter. Gallium nitride (GaN) integrated circuits have significantly increased power densities for monolithic microwave integrated circuits (MMICs) over previous technologies, such as gallium arsenide (GaAs) and other III/V devices. GaN enables improvements in power efficiencies, transmit powers, and higher bandwidths for state-of-the-art radio frequency (RF) electronics and devices.

The U.S. Army Research Laboratory (ARL) has been working with TriQuint Semiconductor, Inc. (TQS) for fabrication under a recent cooperative research and development agreement (CRADA) between ARL and TQS to develop efficient high-PAs for SATCOM applications. A previous report titled *SATCOM and Ka-band Gallium Nitride (GaN) Power Amplifier Monolithic Microwave Integrated Circuit (MMIC)* described several custom GaN broadband PAs at Ka-band (30 GHz) to demonstrate high-efficiency, high-PAs for microwave communications, applicable to SATCOM.[1] Those Ka-band (30 GHz) designs were fabricated in a 0.15-µm high-electron-mobility (HEMT) 4-mil GaN on silicon carbide (SiC) prerelease process that was in development at TQS. A higher-frequency 2-mil GaN on SiC process is being developed with lower inductance, i.e., smaller substrate vias and compact HEMT layouts for better performance at Q-Band (45 GHz) compared to the 4-mil process. Several Q-band amplifier designs were submitted for fabrication in the prereleased 0.15-µm GaN on the 2-mil SiC process. This technical note gives a brief overview of the designs submitted for fabrication that will be followed by a more thorough technical report on the design details of those PAs.

2. Layout of GaN Die

Several PAs for Ka-Band (30–35 Ghz) and Q-Band (45 GHz) operation were designed at ARL using TQS's proprietary 0.15-µm GaN process. All the designs focused on using a 4 × 50-µm HEMT cell with models and load pull data (at 30 and 35 GHz) provided by TQS. A simple one-stage design with a single HEMT was designed, then a two-stage amplifier with two parallel HEMT cells was designed, then a three-stage amplifier with four parallel HEMT cells was designed, etc. Each parallel combination would ideally double the output power, while each

[1] Penn, J. E. *SATCOM and Ka-band Gallium Nitride (GaN) Power Amplifier Monolithic Integrated Circuit (MMIC)*. ARL-MR-0817; U.S. Army Research Laboratory: Adelphi, MD 20783-1197, April 2012.

additional cascaded amplifier stage would multiply the overall gain. TQS offered to fabricate the Q-band amplifiers designed by ARL that would fit in a single 2.6 × 1.6-mm die. This die site allowed for a single stage 4 × 50 Q-band amplifier, a two-stage 2X 4 × 50 Q-band amplifier, a three-stage 4X 4 × 50 Q-band amplifier, and a small broadband 4 × 75 feedback amplifier as shown in figure 1. Combining all of these circuits into a single die assumes probe testing of the four circuits. For packaging of the amplifiers, it would be better if each circuit was an individual die appropriately sized.

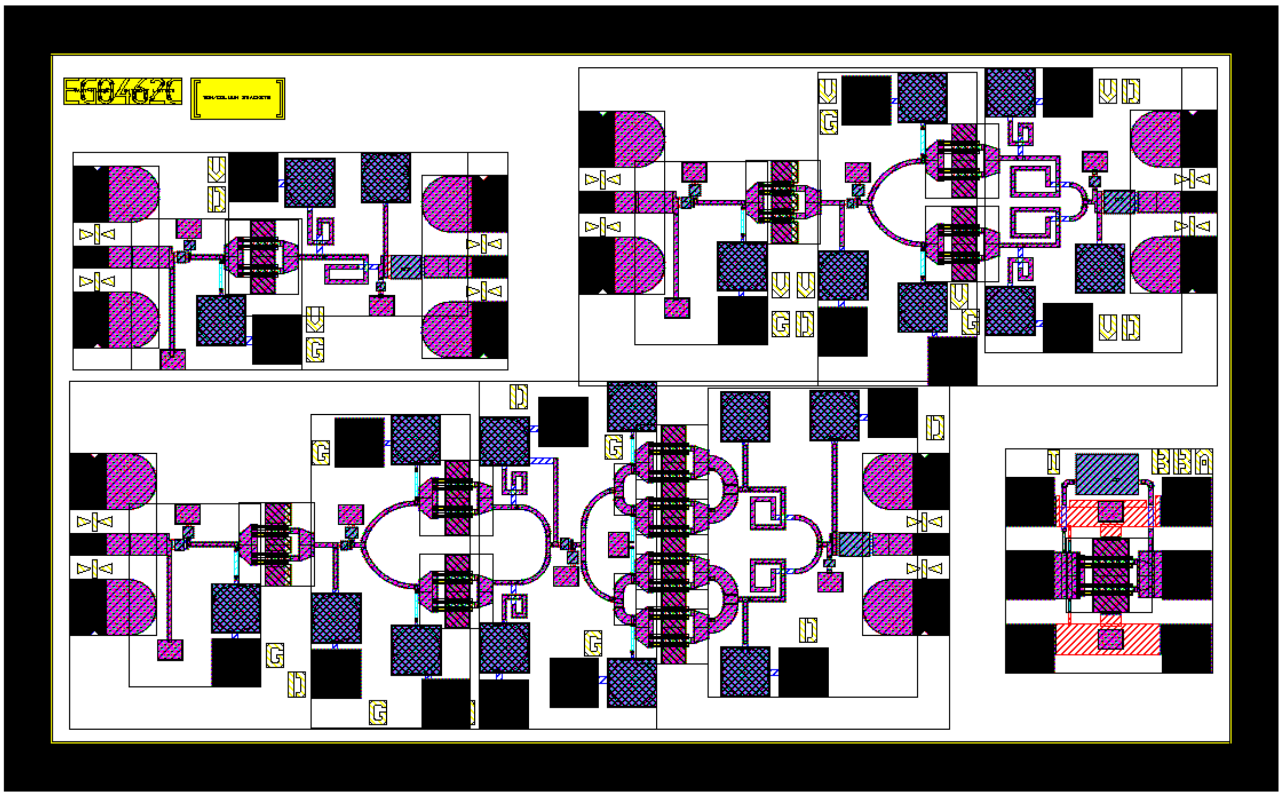

Figure 1. CKT1 45-GHz PAs, plus broadband amplifier (BBA) 2.6 × 1.6 mm.

3. Summary of Designs

The following is a list of the amplifier designs in the die layout:

CKT1—0.2-mm 45-GHz PA, 0.4-mm parallel combined two-stage 45-GHz PA, 0.8-mm parallel combined three-stage 45-GHz PA, and a 0.3-mm BBA (2.6 × 1.6-mm die).

The PAs in CKT1 will be documented in a separate technical report. The BBA is similar to a design fabricated on 4-mil GaN on SiC documented previously in ARL-TN-0497, September 2012.[2] That previous 4-mil design was originally intended to be a broadband high third-order intercept (IP3) low-noise amplifier, but had a larger than intended gain rolloff because of undesired parasitic capacitance on the input and output that was inadvertently added when a design rule error regarding the lengths of two airbridge spans in the feedback path was corrected. This redesign fixes the previous design rule error in the airbridge span lengths without adding significant capacitance that would reduce the gain. The performance in the 2-mil GaN process is expected to be similar, but slightly different, than in the 4-mil process.

4. Design Rule Checking (DRC)

DRC verifies all the layout information to provide for manufacturability. Checks for correct line widths, spacing between polygons within the masks, and checks for appropriate combinations of layers, etc., to ensure a successful design are performed with the DRC software and design rules—both provided by TQS. Initially, the layouts were checked according to the process design rules supplied by TQS, using rules for their released 0.25-µm GaN process. TQS will provide additional design rule checking for their research 0.15-µm GaN on 2-mil SiC process. Currently they are integrating this ARL designed die with their internal TQS designs. There still is the possibility of an electrical error, even with a correct DRC check. This did happen in one or two of the circuits from the previous 4-mil designs. No additional layout versus schematic checking was done for these designs, but this would be expected to be available and necessary when this process is fully released in the future. This is the first ARL submission in this unreleased TQS 0.15-µm GaN on 2-mil SiC process. A follow-on fabrication with the GaN on 2-mil process is expected with additional space for ARL designs in the coming month.

5. Summary

ARL designed and submitted to fabrication several high-efficiency, high-power GaN Q-Band PAs for SATCOM applications and other communications systems. TQS will fabricate these designs under the CRADA between ARL and TQS. Once the designs are returned, they will be tested and documented in future reports. These will be the first designs from ARL using early access to the high-frequency 0.15-µm GaN on 2-mil SiC research process from TQS.

[2]Penn, J. E. *0.15-µm GaN High-Dynamic Range Low-Noise Amplifier Microwave Integrated Circuit Design*. ARL-TN-0497; U.S. Army Research Laboratory: Adelphi, MD, 20783-1197, September 2012.

Earlier broadband GaN amplifiers using TQS's released 0.25-µm GaN process are documented in an ARL technical report titled *Broadband, Efficient, Linear C-Band Power Amplifiers Designed in a 0.15-µm Gallium Nitride (GaN) Foundry Process from TriQuint Semiconductor*.[3] Testing of those designs is documented in an ARL technical report titled *Testing of Two Broadband, Efficient, Linear C-Band Power Amplifiers Designed in a 0.25-µm Gallium Nitride (GaN) Foundry Process from TriQuint Semiconductor*,[4] and led to a paper at the Government Microcircuit Applications & Critical Technology Conference (GOMAC) 2013.[5] Additional reports on the designs using the 0.15-µm GaN process (2- and 4-mil SiC) will be forthcoming.

[3]Penn, J. E. *Broadband, Efficient, Linear C-Band Power Amplifiers Designed in a 0.15-µm Gallium Nitride (GaN) Foundry Process from TriQuint Semiconductor.* ARL-TR-5987; U.S. Army Research Laboratory: Adelphi, MD, 20783-1197, April 2012.

[4]Penn, J. E. *Testing of Two Broadband, Efficient, Linear C-Band Power Amplifiers Designed in a 0.25-µm Gallium Nitride (GaN) Foundry Process from TriQuint Semiconductor.* ARL-TR-6090; U.S. Army Research Laboratory: Adelphi, MD, 20783-1197, August 2012.

[5]Penn, J. E. Broadband C-Band GaN Driver Amplifier. *Government Microcircuit Applications & Critical Technology Conference (GOMAC) 2013*, Session 15, Paper #1, Las Vegas, NV, March 2013.

List of Symbols, Abbreviations, and Acronyms

ARL	U.S. Army Research Laboratory
BBA	broadband amplifier
CRADA	cooperative research and development agreement
DRC	Design Rule Checking
GaAs	gallium arsenide
GaN	gallium nitride
GOMAC	Government Microcircuit Applications & Critical Technology Conference
HEMT	high-electron-mobility
IP3	third-order intercept
MMIC	monolithic microwave integrated circuit
PA	power amplifier
RF	radio frequency
SATCOM	satellite communications
SiC	silicon carbide
TQS	TriQuint Semiconductor, Inc.

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